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# DESIGN AND FABRICATION OF NDE STANDARDS FOR FRACTURE CONTROL

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**ABSTRACT**
Analysis of space flight hardware to determine safety, life, or damage tolerance, requires assumptions concerning flaws which may remain in a part after inspection. Flaw assumptions are based on Probability of Detection (POD) estimates for various geometry's and inspection methods. Acquisition of flaw POD data has historically been limited due to the cost of fabricating realistic flaw specimens. The NDE Laboratory at the Johnson Space Center has developed improved methods for fabricating flaw specimens. NASA has recently given approval for general industry to obtain flaw specimen sets at low cost.

**INTRODUCTION**
The structural integrity of critical NASA space flight hardware is ensured through a damage tolerance program in which component service capability is determined by analysis and/or test. A large percentage of the fracture critical hardware is certified by analysis only. The performance of deterministic fracture mechanics analysis to assess component life requires assumptions about the existence of initial flaws which may remain after inspection at the manufacturer or after inspection in-service. Initial flaw assumptions depend on the nominal capability of inspectors to detect flaw using Nondestructive Testing (NDT) techniques.

**NASA HISTORY OF QUANTITATIVE NDE (QNDE)**
NASA first incorporated fracture mechanics technology during the design of the space shuttle orbiter[1]. Analysis of preliminary designs indicated the need for QNDE to determine initial flaw size assumptions. Three different efforts were performed to collect QNDE data. Due to the high cost of flaw specimens, each effort was performed using the same specimen set. However different analysis techniques were used to meet specified reliability levels (90% Reliability, 95% Statistical Confidence). The final effort was performed by the primary orbiter contractor, Rockwell International. Most flaw size assumptions were based on detection data from penetrant inspections, since it was by far the most widely used NDE method.

**ACQUISITION AND ANALYSIS OF QNDE DATA**
Inspector capability may be inferred by studying individual inspection results from tests using a set of specimens containing flaws with known dimensions. The nominal capability of the general population of inspectors (also called Probability of Detection, POD) is approximated by

grouping a large number of individual test results. This nominal capability is referred to in specifications as standard NDT. A standard NDT flaw size is determined for different flaw geometry's and NDT techniques. Occasionally, flaws smaller than the standard NDT capability must be detected in order to meet life cycle requirements. The capability to find these smaller flaws is called special NDT and must be demonstrated in person to a NASA representative.

A significant number of methods for analysis of QNDT data have been proposed over the last 20 years. NASA has traditionally used an approach based on a binomial distribution which results in a point estimation of POD[2]. It can be shown that if 29 events with two possible outcomes are observed, and all 29 events result in the same outcome, the probability that the same outcome will be observed during any subsequent event under identical conditions is 90% with a corresponding 95% statistical confidence. Another approach was developed by the University of Dayton Research Institute (UDRI) under the direction of the U.S. Air Force[3]. This method is based on the principle of maximum likelihood. A statistical model of POD vs. flaw size was produced based on a large volume of inspection data. Subsequent data is evaluated by calculating input parameters to the model using maximum likelihood equations. The UDRI method may be used to generate a complete POD vs. flaw size curve for each inspector.

Each of these methods are useful under certain conditions. The binomial method is quick and easy to apply, particularly since only a limited number of specimens are required. However, each specimen set is designed to prove the POD of a specific flaw size. The UDRI method is a more complete evaluation of the capability of the inspector. Once the test is completed, the POD for each inspector can be determined for any flaw size. However, at least 80 specimens are required for each UDRI test. If the distribution of flaw sizes in the test set is not adjusted properly, equations to determine inputs to the model may not be solvable. Unfortunately, the adequacy of the flaw distribution is never known until after the test. The U.S. Air Force engine program is based on a calculated risk assessment, therefore knowledge of the inspectors capability to detect any flaw must be known. The UDRI method is called out specifically in the new Air Force Inspection Reliability Standard. By contrast, NASA has previously determined cutoff points for standard NDT and special NDT, therefor the binomial method is used most often for capability demonstrations.

## FABRICATION OF POD SPECIMENS

A practical limitation all POD analysis methods have in common is the requirement for large sets of accurate flaw specimens. Fatigue cracks are generally considered the most difficult flaw to detect for most inspection methods and therefore are used most often in POD specimens. The process for growing a fatigue crack in a controlled environment can be expensive. Commercial costs have typically averaged $1000 per cracked specimen. Consideration of different materials, part geometry's, flaw aspect ratios, and inspection methods, requires huge numbers of specimens. Previous POD data was collected using simple flat plate geometry's, one crack type, and limited inspection methods. POD for other geometry's and inspection methods was extrapolated from this data.

The NDT Laboratory at the Johnson Space Center has developed unique facilities for fabricating realistic flaw specimens, and accumulating and evaluating POD data. New methods for controlled growth of fatigue cracks have dramatically reduced time and cost investment. The primary innovation has been the development of the "scoop-rib" method for initiating fatigue cracks". This idea involves counter-sinking a notched, thin, rib of metal in the surface a flat plate which serves as an initiation point for a fatigue crack. The scoop-rib method produces rapid initiation of a fatigue flaw of known dimensions. Continued growth under specific cycling conditions results in a flaw of known length and aspect ratio.

Significant efforts have also been expended in producing flaws in complicated geometry's such as holes, threads, and rods. One example involves producing a fatigue flaw in a large piece of plate stock from which a finished part is then machined. The finished part may be fabricated so that the flaw ends up at location desired. A continuous effort is in progress to produce large sets of flaw specimens in a large variety of materials and geometry's. POD data is collected on these specimens from inspections performed by NASA contractors. This data is used to update initial flaw size assumptions for fracture analysis.

**SUMMARY**

These innovations have led JSC to promote the widespread distribution of NDE specimens throughout the NASA community. Under this philosophy, all contractors are encouraged to demonstrate POD capability by requesting the loan of specimens from JSC. Test results remain confidential, and inspectors who do not meet the required confidence level can be retested after additional training. JSC standards are also available to general industry. Standards may be requested from the JSC NDT Laboratory by any organization on the condition that NASA is allowed to add the inspection data collected to the JSC flaw detection database. Under certain conditions, flaw specimens may be acquired permanently by outside organizations.

**REFERENCES**


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